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Simulation and examination of energy and exergy performance of combined power generation cycle by ASPEN HYSYS software

Farzin Hosseinifard[1], Mostafa Omidi bidgoli[2*]

[1] Department of Mechanical Engineering, K.N.Toosi university of technology, Tehran, Iran
[*2] Department of Mechanical Engineering, Badroud Branch, Islamic Azad University, Badroud, Iran

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Extended Abstract

Introduction

The rapid growth in global energy demand in recent years, accompanied by strict environmental constraints, has intensified the need for high-efficiency power generation systems. According to international energy reports, energy demand has increased significantly, necessitating solutions that simultaneously reduce pollutant emissions. Excessive carbon dioxide emissions have led to severe environmental consequences, including global warming, ozone layer depletion, forest fires, and acid rain. Consequently, reducing carbon emissions has become a primary objective for both governments and large industries.
Among various mitigation strategies, the deployment of combined cycle power plants has attracted considerable attention due to their high thermal efficiency, reduced fuel consumption, and relatively lower maintenance requirements. Although combined cycle systems offer substantial energy efficiency improvements, conventional energy analysis alone is insufficient to identify internal inefficiencies. Therefore, exergy analysis is essential to evaluate system irreversibilities and pinpoint components with significant exergy destruction.
The main objective of this study is to evaluate the energy and exergy performance of a combined power generation cycle and to identify the components responsible for major exergy losses in order to enhance overall system efficiency. In this work, the power generation cycle is simulated using Aspen Hysys software, selected for its strong capability in modeling organic working fluids. A key novelty of this study is the use of pentane as the organic working fluid, which has been less frequently investigated in similar research. The impact of working fluid selection on system irreversibilities and exergy destruction is comprehensively analyzed.

Materials and Methods

In this study, a combined cycle power generation system with a total output capacity of 66 MW was simulated under steady-state conditions using Aspen Hysys software. Following the simulation, energy and exergy analyses were conducted to evaluate the system efficiency and to quantify exergy destruction within individual components. Exergy analysis is recognized as a rigorous thermodynamic approach that assesses the quality of energy conversion and identifies sources of irreversibility within energy systems.
To perform the energy and exergy analyses, a set of fundamental assumptions was initially defined, and mass, energy, and exergy balance equations were applied in accordance with the first and second laws of thermodynamics. The reference environmental conditions were assumed to be 1 bar pressure and a temperature of 298 K. The total exergy of the system was considered as the sum of physical and chemical exergy components, while exergy efficiency was evaluated based on the ratio of product exergy to fuel exergy.
The exergy assessment of the system was carried out using the fuel–product approach. Within this framework, the fuel stream enters the control volume, useful work is produced or absorbed, and the product stream exits the system. Exergy destruction, representing system irreversibilities, is treated as an additional output stream. This approach provides a clear basis for identifying inefficiencies and improving the overall performance of the combined cycle power generation system.

Results and Discussion

Exergy analysis, alongside energy analysis, plays a fundamental role in evaluating the actual performance of power generation systems. While energy analysis focuses on energy conservation based on the first law of thermodynamics, exergy analysis emphasizes useful work potential and overall system efficiency. A system may satisfy energy balance requirements; however, it must also exhibit acceptable exergy efficiency and limited irreversibilities to be considered thermodynamically efficient.

The exergy analysis of the combined power cycle components indicates that higher exergy efficiency corresponds to lower system irreversibilities. Due to their thermal nature, certain components—particularly heat exchangers and turbines—exhibit significant exergy destruction. Exergy destruction represents the loss of the ability of energy to be converted into useful work and is especially pronounced in thermal equipment. Therefore, energy systems are commonly evaluated as control volumes to achieve a more accurate assessment of efficiency and irreversibility distribution. Exergy analysis thus provides a valuable framework for identifying optimization opportunities aimed at reducing losses and improving system performance.
The overall exergy efficiency of the combined cycle was calculated to be 83%, indicating a high level of performance and effective energy conversion. Among the system components, the heat recovery exchanger exhibited the highest exergy efficiency of approximately 91%, attributed to its optimized design and effective heat recovery capability. In contrast, turbines demonstrated comparatively lower efficiencies due to technical complexities, operational conditions, and inherent energy losses during the conversion process.
The distribution of exergy destruction among system components reveals that the first steam turbine accounts for the largest share of total exergy destruction, contributing approximately 44% of the overall system losses. This is followed by the second turbine and the heat recovery exchanger, accounting for 28% and 26% of the total exergy destruction, respectively. Such findings highlight the critical components requiring targeted optimization.
Furthermore, the exergy efficiency of the thermal cycle obtained in this study was compared with results reported in previous investigations, including those by Esmaeili et al. [20] and Ashrafizadeh et al. [21], which focused on efficiency enhancement in thermal and combined cycles. The comparison demonstrates that the present study achieves competitive and improved performance relative to similar systems reported in the literature.

Conclusion

The increasing level of carbon emissions in power generation industries has driven these systems toward combined cycles to improve overall efficiency. One of the major challenges in such cycles is the relatively low exergy efficiency and the associated energy destruction within system components. The results of the present study indicate that the overall performance of the investigated cycle is satisfactory, with a total efficiency of approximately 82%. Exergy analysis revealed that the highest share of exergy destruction, accounting for about 44%, occurs in the first turbine, identifying this component as a primary candidate for system optimization. In addition, pentane was employed as an intermediate working fluid to evaluate its influence on system irreversibilities. The exergy assessment demonstrated that the use of this novel working fluid does not lead to a significant increase in irreversibilities within the system. Moreover, from an economic standpoint, pentane was found to be a viable and attractive option for application in power generation cycles.

Key words: Power plant, combined cycle, energy, exergy, efficiency, Aspen hysys

*mostafaomidibidgoli@gmail.com

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